Two New Low Redshift 21cm Absorbers

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ABSTRACT

As part of a larger program to identify low redshift radio analogues of the damped Lyman$-\alpha$ (DLA) absorbers seen in the spectra of high redshift quasars, Westerbork Synthesis Radio Telescope (WSRT) observations have discovered two new HI 21cm absorption lines at $z = 0.394$ and $z = 0.437$ in the spectra of the radio sources B 0248+430 and B 1243-072 respectively. These sightlines and redshifts were selected for study on the basis of the previously known low ionization absorption lines of Mg II, and neither has been observed in the Lyα line. The 21cm line observations provide information on column densities, temperatures and kinematics of the thickest cold neutral clouds in the absorbers.

Subject headings: quasars: absorption lines — quasars: individual(B0248+430, B1243-072) — galaxies:ISM

1. Introduction

The identification of redshifted QSO absorption line systems with $N_{\rm HI} \geq 2 \times 10^{20}$ cm^{-2}, typically referred to as damped Lyα (DLA) systems, is important because the DLA absorbers are thought to be the progenitors of present day ordinary galaxies. The nature of these high neutral H I column density systems is under debate. At high redshift, study of the absorbers is made difficult by the dimness of the protogalactic systems, and much of the work is theoretical (eg. Prochaska & Wolfe 1998; Haehnelt, Steinmetz, & Rauch 1998). At low redshift there are fewer absorbers known, and recent observations find a variety of host galaxy types, including amorphous low surface brightness galaxies as well as spirals and compact objects, (eg. Steidel et al. 1995; Le Brun et al. 1997; Bowen, Tripp & Jenkins 2001; Turnshek et al. 2001). Thus there is a need to identify more local, low and moderate redshift examples for detailed study.

One way to identify these systems is to select low-redshift absorbers by the presence of another, more common, low-ionization absorption line such as the Mg II $\lambda\lambda 2796, 2803$ Å doublet. The metal-line systems can then be observed in either the UV regime for DLA absorption against QSO's with sufficient UV flux (eg. Rao & Turnshek 2000), and/or in the radio for H I 21cm absorption if the QSO is also a radio source (Lane et al. 2001, in prep). Unlike the saturated DLA absorption feature, the 21cm absorption profile can provide information about the velocity and temperature of the absorbing clouds (eg. Lane, Briggs, & Smette 2000; Briggs, de Bruyn, & Vermeulen 2001). The radio-emitting region in a QSO is extended, so H I21cm observations at the appropriate angular resolution can also provide information on the spatial distribution of the absorbing gas by probing several sightlines to the background source. If the information on velocity structure and spatial distribution of the gas is combined, it is possible to construct a reasonable model of the intervening galaxy responsible for the absorption (eg. Briggs et al. 2001).

The opacity of the 21cm line is inversely sensitive to the excitation or spin temperature, T_s, of the gas; lower T_s gas will create a more opaque absorption profile. Under usual conditions in the multi-temperature-phase interstellar medium (ISM) of the Milky Way, T_s is coupled to the kinetic temperature, T_k, of cold-phase gas (Dickey & Lockman 1990), although the two temperatures begin to diverge in the case of warm-phase ISM gas (Liszt 2001). As a result, the 21cm line profile can be used to estimate the kinetic temperature of the cold neutral absorbing gas to which it is most sensitive. This can be done either by comparison to the temperature-insensitive DLA absorption line in the same system, or by using the width of each individual component to set an upper limit to the kinetic temperature of the gas (Lane et al. 2000; Kanekar, Ghosh, & Chengalur 2001).

Currently, there are roughly 25 redshifted 21cm absorbers known. Of these roughly one-third have absorption redshift $z_{abs} \approx z_{em}$, the QSO redshift, indicating that the absorption occurs in the QSO host galaxy. The rest are systems which intervene along the sightline to a QSO. In this paper we present high velocity resolution radio spectra for two new intervening low-redshift H I 21cm absorbers identified in a recent survey (Lane 2000). Neither object has been observed for Lyα absorption, but we infer that both have column densities $N_\mathrm{HI} \geq 2 \times 10^{20}$ cm^{-2}.

2. Deriving the Column Density

The neutral column density contained in a 21cm absorption line is computed by taking the integral over the absorption profile:

$$N_\mathrm{HI} = 1.8 \times 10^{18}\ T_\mathrm{s} \int \tau(v)\ dv \ \ \mathrm{cm}^{-2} \qquad (1)$$

where T_s is the spin temperature of the absorbing gas, assumed to be constant for each cloud, and v is the velocity in km s^{-1}. $\tau(v)$ is the optical depth of the line at velocity v, and includes a factor f to account for the fraction of the continuum source covered by the absorber.

Thermal broadening of an absorption feature provides an independent constraint on the kinetic temperature, $T_\mathrm{k} \approx T_\mathrm{s}$, of the gas:

$$T_\mathrm{k} \leq 21.855 \times \Delta v^2 \ \ \mathrm{K} \qquad (2)$$

where Δv is the full-width half max (FWHM) velocity for atomic Hydrogen measured in km s^{-1}. Unfortunately, bulk kinematical motions and turbulence in the absorbing H I gas will also broaden the absorption line, so this is not always a stringent constraint on the gas temperature.

3. The Data

The 21cm spectra were obtained on 1999 September 19 (B 0248+430) and 2000 September 6 (B 1243-072) using the Westerbork Synthesis Radio Telescope (WSRT)[1] with UHF-high receivers and the DZB correlator. Both observations were made as followups to previous and more tentative detections from an extensive 21cm survey of Mg II absorbers by Lane (2000).

For B 0248+430, the total integration time was just under 4 hours. A bandwidth of 0.625 MHz centered at 1018.94 MHz is divided into 256 channels to provide a channel width of 2.44 kHz. No on-line smoothing was applied, giving a velocity resolution of 0.86 km s^{-1}. Observations of 3C 48 were used to calibrate the flux density scale and the passband. For B 1243-072, the total integration time was roughly 9.5 hours. A bandwidth of 1.25 MHz and 128 channels centered at 988.6 MHz give a velocity resolution of 3.6 km s^{-1}. Observations of 3C 147 were used to calibrate the flux and bandpass.

Using standard routines in AIPS, both data sets were self-calibrated to line-free continuum maps. After removing the continuum emission, map cubes were made and spectra extracted at the positions of the QSOs. The final spectra, offset to indicate the measured continuum flux, are shown in Figures 1 and 2.

4. B 0248+430, $z_{abs} = 0.3941$

B 0248+430 is a core dominated quasar at an emission redshift $z_{em} = 1.31$. The metal line system at $z_{abs} = 0.394$ was originally identified in a spectrum taken to study absorption associated with a pair of merging galaxies that lie close to the QSO sightline at $z = 0.05$ (Womble et al.

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Table 1: The Four Component Fit to the B 0248+430 21cm line Profile

Component	Δ V$_{offset}$ (km s^{-1})	τ_{21}	FWHM Δv (km s^{-1})	$\int \tau(v)\ dv$ (km s^{-1})	$T_{\rm k}$ (K)
1	0	0.20 ± 0.03	4.3 ± 0.4	0.92 ± 0.16	405 ± 75
2	17.8 ± 0.6	0.16 ± 0.03	6.2 ± 0.4	1.05 ± 0.21	840 ± 110
3	31.0 ± 0.6	0.12 ± 0.03	6.9 ± 0.4	0.88 ± 0.23	1040 ± 120
4	-6.2 ± 0.6	0.07 ± 0.03	1.9 ± 0.4	0.14 ± 0.07	79 ± 33

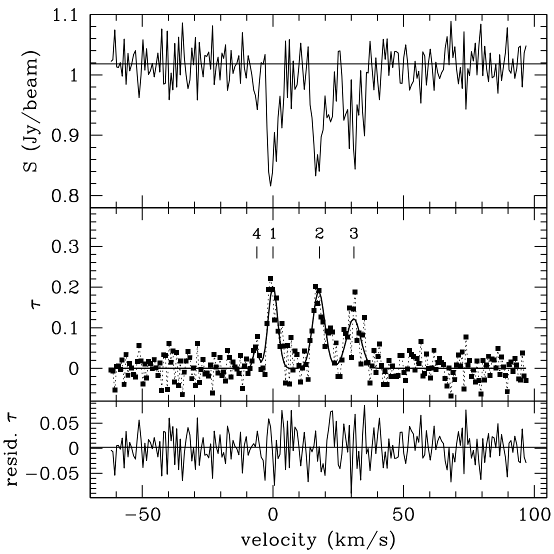

Fig. 1.— WSRT/DZB high resolution spectrum of the $z = 0.3941$ H I 21cm absorber toward B 0248+430 at a channel spacing of 2.44 kHz, or a velocity resolution of 0.81 km s^{-1}. $v = 0$ is placed at the metal-line redshift of $z = 0.394$. The top panel shows the original spectrum. The middle panel shows the optical depth of the lines, with the data points connected by a light dotted line. The heavy solid line shows the fit, and the centroids of the individual components listed in Table 1 are marked. The bottom panel shows residuals after the fit has been subtracted.

1990). The initial detection of Mg II and Mg I at $z_{abs} = 0.394$ was confirmed, and Fe II and Ca II absorption lines at the same redshift were reported by Sargent & Steidel (1990). At present, there is no reported detection (or significant non-detection) of the DLA line for this system. For this reason there is no temperature independent measure of the total neutral column density in this system.

The H I 21cm absorption feature is composed of a complex of lines, roughly clustered in three groups, which combined cover ~ 40 km s^{-1}. The 3σ noise in the spectrum is equivalent to an optical depth, $\tau_{3\sigma} = 0.09$. The best simultaneous 4-Gaussian fit to the data is shown in Figure 1, and the fitted line parameters are listed in Table 4. We have placed the system velocity, $\Delta V = 0$, at a frequency of 1018.94 MHz, corresponding to both the center of the deepest absorption component and the metal-line redshift of $z_{abs} = 0.394$. Conservative errors for τ are estimated from the RMS of the residuals. The errors on Δv are taken to be one-half of a resolution element, and we assume that the gas covers the entire QSO ($f = 1$).

The 21cm line integral, $\int \tau(v)\ dv = 2.99 \pm 0.36$ km s^{-1}, leads to an estimated column density of $N_{\rm HI} = 5.4 \pm 0.6 \times 10^{18} \times < T_{\rm s} >$ atoms cm^{-2} K^{-1}. We use the notation $< T_{\rm s} >$ to indicate a column-density-weighted harmonic mean spin temperature for all of the absorbing gas along the sightline. Even if the spin temperature of each component is as low as $T_{\rm s} \sim 100$ K, a "typical" value for cold-phase gas (Dickey & Lockman, 1990), this system would have a total $N_{\rm HI} \approx 5 \times 10^{20}$ cm^{-2}. Carilli et al. (1996) find $< T_{\rm s} > \approx 1000$ K to be more typical in redshifted DLA/21cm absorbers, suggesting the true column density is even higher.

The fitted absorption component widths are narrow enough to use Eq. 2 to calculate reasonable upper limits to $T_{\rm k}$ for each. These are listed in column 6 of Table 4. Setting $T_{\rm s} \leq T_{\rm k}$, we sum the derived column density for each of the 4 components and find a total column density $N_{\rm HI} \leq 3.9 \pm 0.6 \times 10^{21}$ cm^{-2} is contained in the detected profile. This estimate is an upper limit because the lines may be broadened by bulk kinematical motions as well as thermal motions. On the other hand, we could be excluding a significant column density of warm-phase H I which would create a broad shallow absorption component not detected at the sensitivity levels of this spectrum (Lane et al. 2000).

Optical and/or infrared followup of this absorber is made difficult by the $z = 0.05$ interacting galaxy pair, which includes a long tail that crosses the QSO sightline. Although many images of this field have been published (eg. Borgeest et al. 1991, Kollatschny et al. 1991), few candidate absorbers are known. There is a small object roughly 1" south of the QSO in an HST PC image (Maoz et al. 1992), and a galaxy superimposed on the foreground tidal tail (Sargent & Steidel 1990). The closest two objects which are easily distinguished from the tidal tail are a $z = 0.240$ galaxy to the Northeast and a compact, probably stellar object to the South (Womble et al. 1990). It seems unlikely that further ground-based imaging and spectroscopy will identify the $z = 0.394$ absorbing galaxy; space-based observations will be necessary to identify candidate hosts against the extended low surface brightness tidal tail.

At radio wavelengths, the background quasar can be resolved into a double-lobed source with a separation along the northwest/southeast axis of $\sim$12 mas at a frequency of 2 GHz (Fey & Charlot 2000). Mapping of the complex absorption against the two components will provide information about the gas structure on a roughly 60 pc scale.

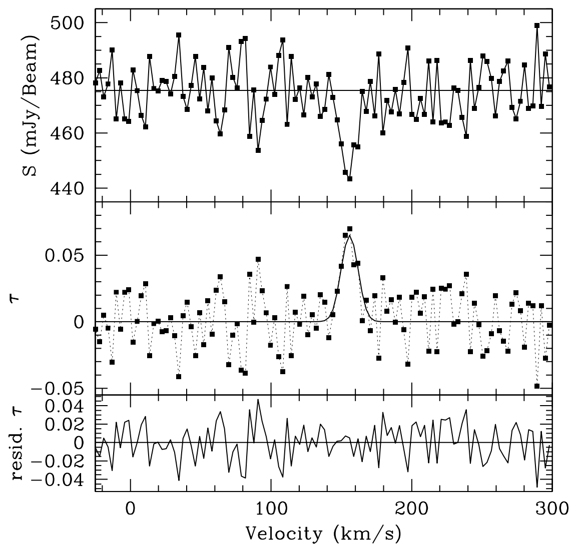

Fig. 2.— WSRT/DZB spectrum of the $z = 0.4367$ H I 21cm absorber toward B 1243-072 at a channel spacing of 9.8 kHz, or a velocity resolution of 3.6 km s^{-1}. The velocity scale has been chosen such that $v = 0$ corresponds to $z = 0.436$, the metal-line redshift. The top panel shows the original spectrum. The middle panel shows the optical depth of the line, with the data points connected by a light dotted line, and a heavy solid line indicating the Gaussian curve we have fit to the data. The bottom panel shows residuals after the fit has been subtracted.

5. B 1243−072, $z_{abs} = 0.4367$

B 1243-072 is a core-dominated quasar with an emission redshift $z_{em} = 1.29$. At 20cm it may have weak radio lobes extending $\sim$ 5" to the east and west (Gower & Hutchings 1984; cf. Browne & Perley 1986); it is certainly unresolved by the $\sim$23" resolution of the WSRT at this frequency. The metal-line system at $z = 0.436$ was originally identified by Wright et al. (1979), and contains the Mg II $\lambda\lambda 2796, 2803$ doublet, and several Fe II absorption features. No measured equivalent widths are reported for this early low-resolution spectrum; in fact the Mg II doublet is reported as a single line. No subsequent spectra for this source have been published.

The detected H I 21cm absorption is shown in Figure 2. The 3σ feature lies at a heliocentric frequency of 988.60 MHz, corresponding to a redshift $z_{abs} = 0.4367$. This is offset by some 160 km s^{-1} from the reported metal-line redshift, probably due to the low precision of the optical measurement. The 21cm line is several channels wide and increases in significance to 5σ after the spectrum is Hanning smoothed to 7 km s^{-1} velocity resolution. A weak absorption feature has been present at the same heliocentric frequency in two other, lower-quality, WSRT spectra of this source (Lane 2000).

The absorption feature can be modelled as a single Gaussian component with FWHM velocity $\Delta v = 14.1 \pm 1.8$ km s^{-1} and optical depth $\tau = 0.065 \pm 0.020$, assuming a covering factor $f = 1$. Errors for τ are estimated from the RMS of the residuals, and the errors on Δv are taken to be one-half of a resolution element. Using these parameters we find a total H I column density $N_{\rm HI} = 1.7 \pm 0.6 \times 10^{18} \times < T_{\rm s} >$ cm^{-2}. We expect $< T_{\rm s} >$, the harmonic mean spin temperature of all the gas in the absorption profile, to be some-where between the single cloud value $T_s = 100$ K, and $< T_s > = 1000$ K (eg. Carilli et al. 1996). We conclude that this system has a column density consistent with that of at least a weak DLA absorber.

This system is ideal for detailed optical and radio follow-up study. The quasar is only moderately bright (V = 18), making it relatively easy to study sources quite close to the QSO sightline. Currently, the only published image of this field comes from the Digitized Sky Survey (DSS)[2], and the surrounding field appears relatively uncrowded. There are only three or four very faint objects and one small bright object within a projected radius of 25" from the QSO sightline. In addition there is a large foreground disk galaxy at a projected separation of about 1'.

Observations at a frequency of 2 GHz show a 20 mas extension to the west of the radio quasar, making it a suitable candidate for very long baseline interferometry (VLBI) mapping of the 21cm absorption (Fey & Charlot 2000). Moderate baseline mapping might also be able to trace absorption against the weak 5" scale radio lobes (Gower & Hutchings 1984).

6. Conclusions

We present two new H I 21cm absorbers. These add to a small but growing group of high neutral column density systems at low and moderate redshifts. Both of these systems are suitable for further detailed study which can contribute to our understanding of the types of galaxies responsible for 21cm/DLA absorption and the evolution of H I-rich galaxies.

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REFERENCES

Borgeest, U., Schramm, K.-J., Dietrich, M., Kollatschny, W., & Hopp, U. 1991, A&A, 243, 93

Bowen, D. V., Tripp, T. M., & Jenkins, E. B. 2001, AJ, 121, 1456

Briggs, F. H., de Bruyn, A. G., & Vermeulen, R. C. 2001, A&A, 373, 113

Browne, I. W. A. & Perley, R. A. 1986, MNRAS, 222, 149

Carilli, C. L., Lane, W., de Bruyn, A. G., Braun, R., & Miley, G. K. 1996, AJ, 111, 1830

Dickey, J. M. & Lockman, F. J. 1990, ARA&A, 28, 215

Fey, A. L. & Charlot, P. 2000, ApJS, 128, 17

Gower, A. C. & Hutchings, J. B. 1984, AJ, 89, 1658

Haehnelt, M. G., Steinmetz, M., & Rauch M. 1998, ApJ, 495, 647

Kollatschny, W., Dietrich, M., Borgeest, U., & Schramm, K.-J. 1991, A&A, 249, 57

Kanekar, N. and Ghosh, T. & Chengalur, J. N.

Lane, W.M., 2000, Ph.D thesis, Univ. of Groningen

Lane, W., Briggs, F., & Smette, A. 2000, ApJ, 532, 146

Le Brun, V., Bergeron, J., Boisse, P., & Deharveng, J. M. 1997, A&A, 321, 733

Liszt, H. 2001, A&A, accepted, astroph/0103246

Maoz, D., Bahcall, J. N., Doxsey, R., Schneider, D. P., Bahcall, N. A., Lahav, O. & Yanny, B. 1992, ApJ, 394, 51

Prochaska, J.X., & Wolfe, A.M. 1998, ApJ, 507, 113

Rao, S. M. & Turnshek, D. A. 2000, ApJS, 130, 1

Sargent, W. L. W. & Steidel, C. C. 1990, ApJ, 359, L37

Steidel, C.C., Bowen, D.V., Blades, J.C., & Dickenson, M. 1995, ApJ, 440, L45

Turnshek, D.A., Rao, S., Nestor, D., Lane, W.M., Monier, E., Bergeron, J., & Smette, A. 2001, ApJ, 553, 288

[2]The Digitized Sky Surveys were produced at the Space Telescope Science Institute under U.S. Government grant NAG W-2166.

Womble, D. S., Junkkarinen, V. T., Cohen, R. D., & Burbidge, E. M. 1990, AJ, 100, 1785

Wright, A. E., Peterson, B. A., Jauncey, D. L., & Condon, J. J. 1979, ApJ, 229, 73

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